



DER and Microgrids: Research Topics within EU Framework Programs

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Sustainable Energy Systems DRIVING FORCES

■ Energy Policy:

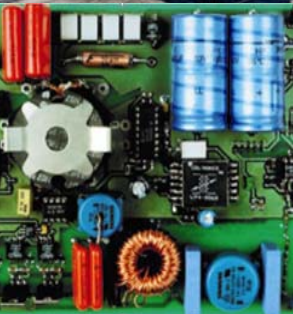
- Market liberalisation and competitiveness
- External dependency and security of supply
- Energy efficiency and technological development

■ Environment Policy:

- Kyoto and Göteborg commitments for a sustainable development

■ R&D&T and innovation Policy:

- Lisbon Strategy and the European Research Area





Sustainable Energy Systems

Legislative instruments



- **Electricity internal market, 97/98 & 2003**
- **Electricity from RES, September 2001**
- **Energy efficiency in buildings, December 2002**
- **Bio-fuels for transport, May 2003**
- **Emission right trade, Oct 2003**
- **Co-generation, February 2004**



Drivers for Energy Research in EU

Security of supply

- ✓ 50% external dependence
- ✓ reliance on fossil fuels
- ✓ need diversification of sources (RES)

Climate change

- ✓ “one of the greatest challenges of our generation”
- ✓ energy \leftrightarrow CO₂
- ✓ need clean energy (RES)

Competitiveness of the European industry

- ✓ competitiveness (Lisbon objectives)
- ✓ sustainable development
- ✓ energy is a growth market (RES)



Key considerations for “Electricity with large DER”

- ❑ Security of supply – efficient mix of centralised with decentralised operation allows the use of domestic energy resources, whilst maintaining a high level of reliability and quality of supply.
- ❑ Climate change – higher efficiency in energy transport and use of RES and cleaner Distributed Generation, incl. CHP, results in a real contribution to reduce emissions.
- ❑ Competitiveness of European Industry – enhancement and renewal of the electricity infrastructure networks represents a huge investment/markets, both in the EU and worldwide.



RTD Electricity in FP5-6:

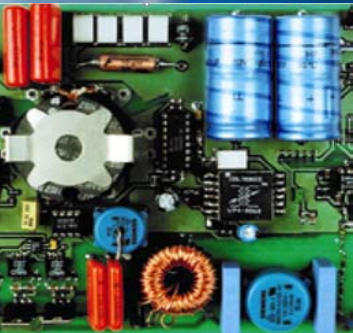
large scale“integration” of RES+DG

- ❑ Validation of advanced grid architectures
- ❑ Large Scale Virtual Power Plants
- ❑ Network of Excellence for DER laboratories
- ❑ Co-ordination Action for European DER
- ❑ Power electronics
- ❑ High Temperature Superconductivity
- ❑ Future European Electricity Transmission Networks





FP5 (1998-2002) funded research large-scale “integration” of RES+DG



Research Area: INTEGRATION DER	Number of projects	Total Budget [M€]	EC funding [M€]
Distributed Generation	8	34.29	18.99
Transmission	4	9.74	5.72
Storage	20	45.31	20.73
HT Superconductors	6	11.27	6.16
‘Other’	17	29.12	15.21
TOTAL	55	129.73	66.81

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FP6 (2002-2006) funded research large-scale Integration of RES+DG



Research Area: INTEGRATION DER	Number of projects	Total Budget [M€]	EC funding [M€]
Advanced Architectures and Operation concepts	7	65.50	33.35
Transmission	2	7.07	4.95
Storage	1	5.87	5.00
HT Superconductor Devices for networks	2	7.82	3.35
Advanced Power Electronics	2	5.25	3.41
TOTAL	14	91.51	50.06

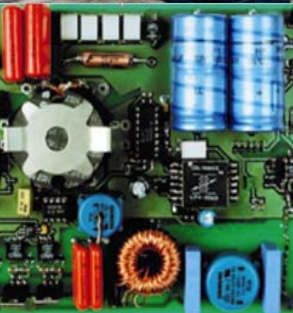
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Main lessons learned so far

FP5&6 funded research large-scale Integration of RES+DG

- Non-technical issues are critical today
- Main technical issues are reliability, safety and quality of power
- Real-time information is critical
- Few possible concepts for smart power grids, but final solutions still unclear
- Impact on transmission networks should be further considered.
- Emerging results are being exploited
- International dimension recognized under ERA
- Co-operation and co-ordination of stakeholders in the context of a Technology Platform



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Cooperation – Collaborative research

9 Thematic Priorities

DRAFT

- 1. Health**
- 2. Food, agriculture and Biotechnology**
- 3. Information and Communication Technologies**
- 4. Nanosciences, Nanotechnologies, Materials and new Production Technologies**
- 5. Energy**
- 6. Environment and climate change**
- 7. Transport**
- 8. Socio-Economic Sciences and the Humanities**
- 9. Space and Security research**



5. Energy

DRAFT

Hydrogen and fuel cells

Renewable electricity generation

Renewable fuel production

Near zero emission power generation

Smart energy networks

Energy savings and energy efficiency

Knowledge for Energy policy making



Preparation of FP7

Smart Power Networks: Research and demonstration needs for “Integration” of DER/RES.

- **Aimed at removing all obstacles to larger development of DER/RES**
- **Ensure functioning of the EU electricity market, addressing the issues of security, reliability and quality of supply**
- **Provide appropriate knowledge for technical solutions and regulatory approaches.**



5th (EC) RTD Framework Programme (1998-2002)

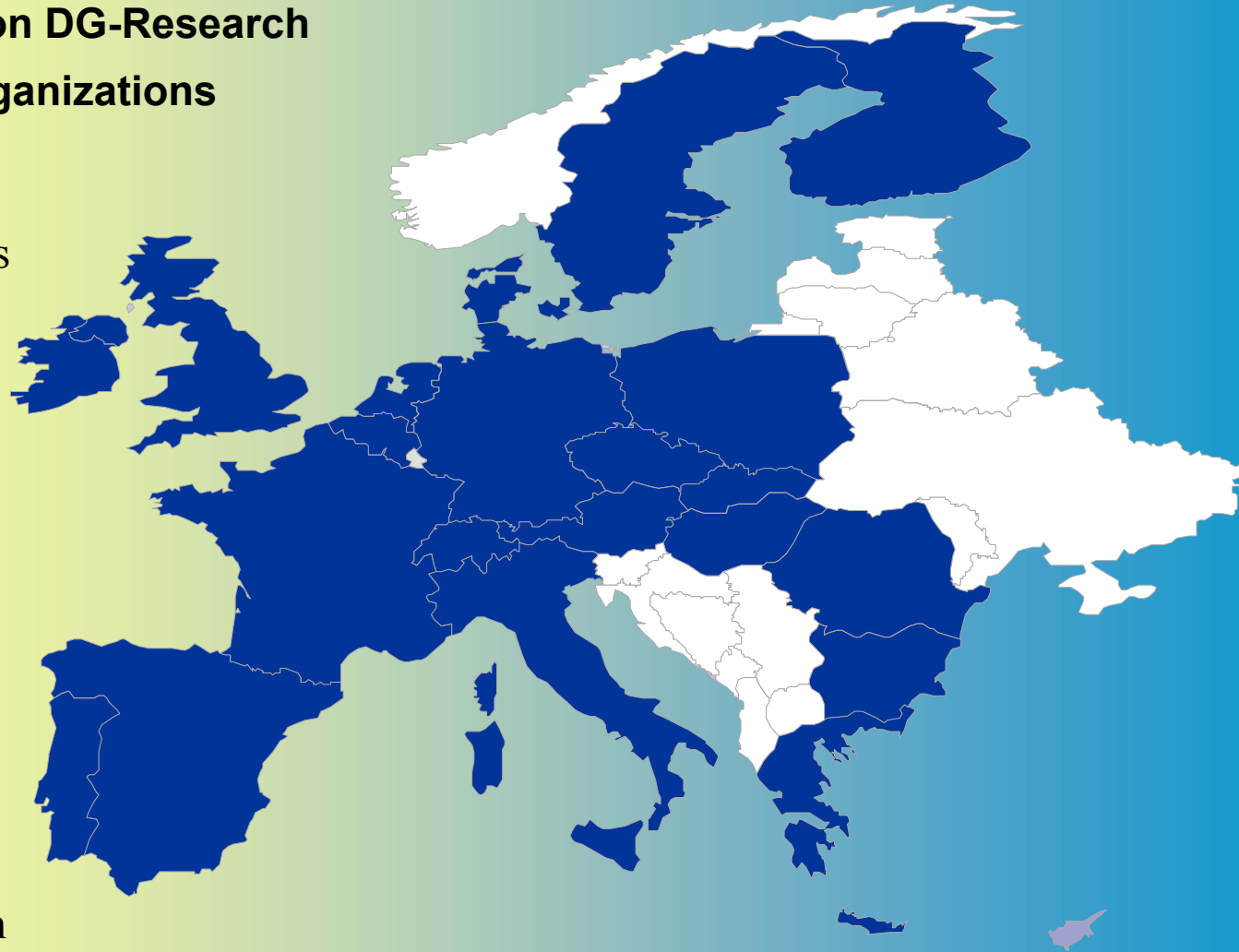
“Integration of Renewable Energies + Distributed Generation”

European Commission DG-Research

Over 100 different organizations

34 Mio. Euro

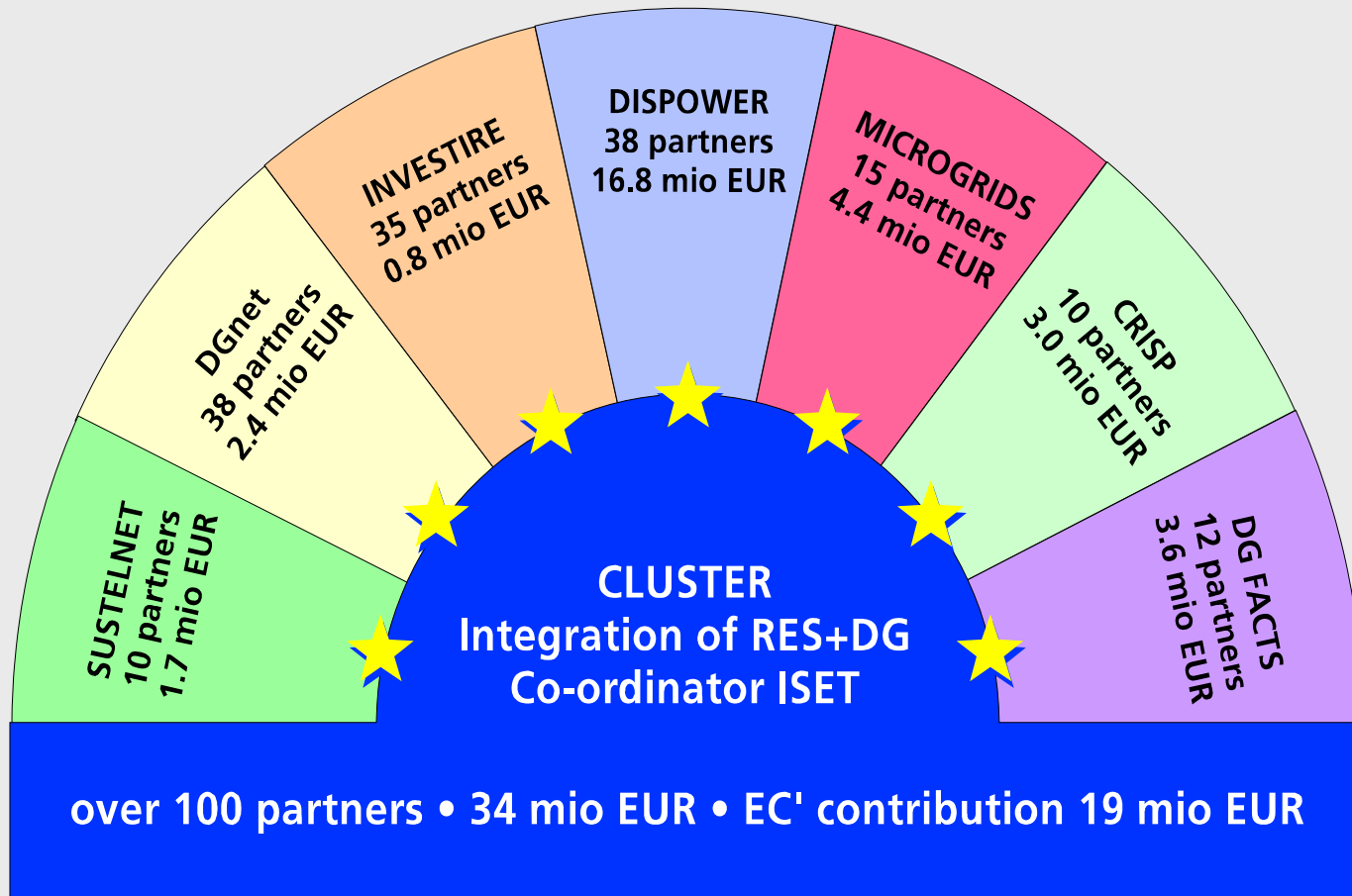
- Concentrating efforts and maximising critical mass
- Creating real European added value in support of European policy making towards mobilising research
- Identifying highest priority research topics in this field
- Improving links with policies and schemes





Cluster

“Integration of Renewable Energies + Distributed Generation”

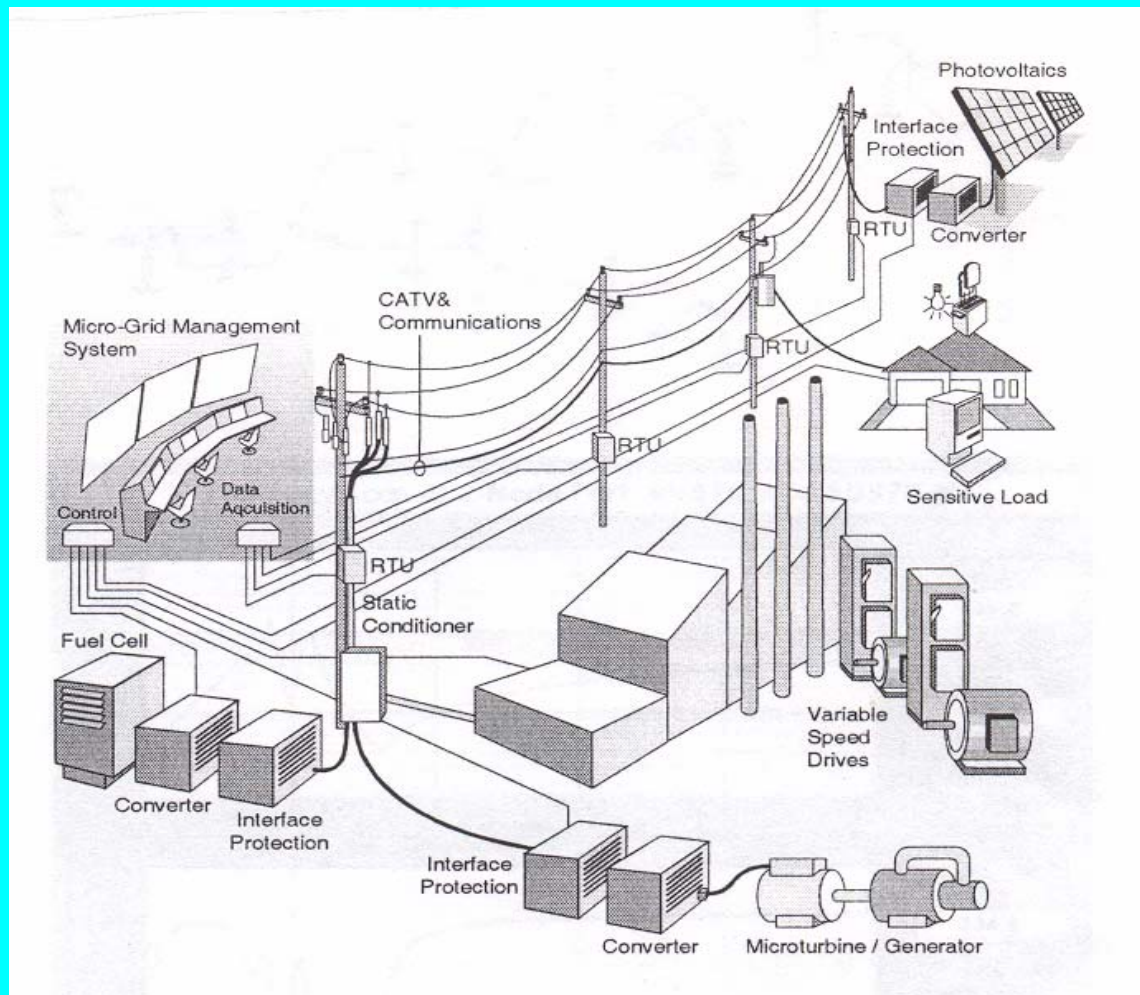




What are MICROGRIDS?

Interconnection of small, modular generation to low voltage distribution systems forms a new type of power system, **the Microgrid**.

Microgrids can be connected to the main power network or be operated islanded, in a coordinated, controlled way.





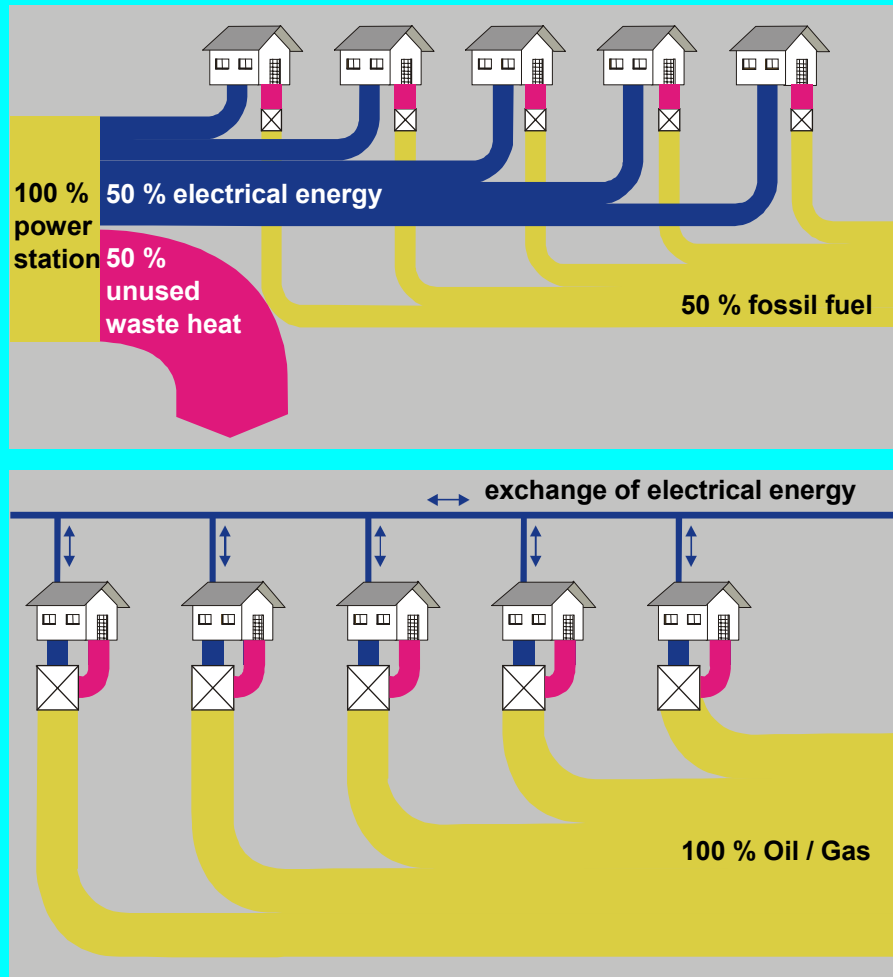
Technical, economic and environmental benefits

- Energy efficiency
- Minimisation of the overall energy consumption
- Improved environmental impact
- Improvement of energy system reliability and resilience
- Network benefits
- Cost efficient electricity infrastructure replacement strategies
- *Cost benefit assessment*



Energy Efficiency - Combined Heat and Power

Prof. Dr. J. Schmid



Up to now:

- Central power stations
- Decentral heat production

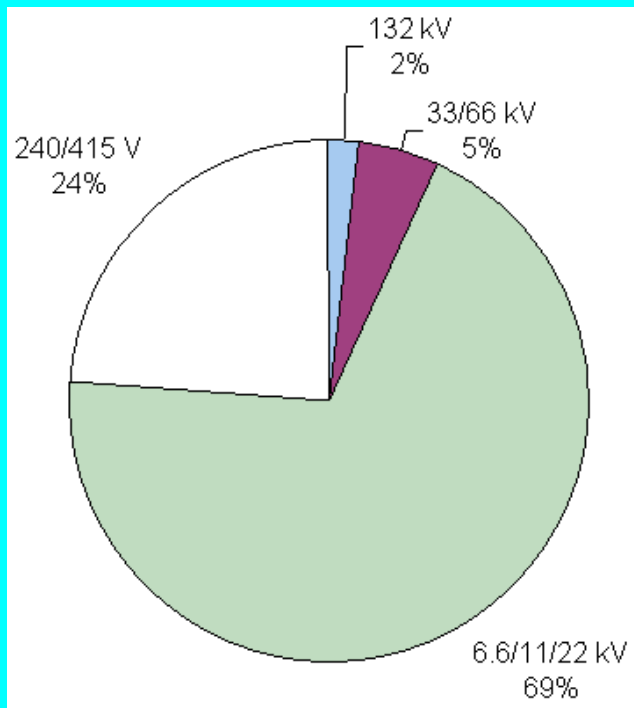
In Future:

- Decentral combined heat and power

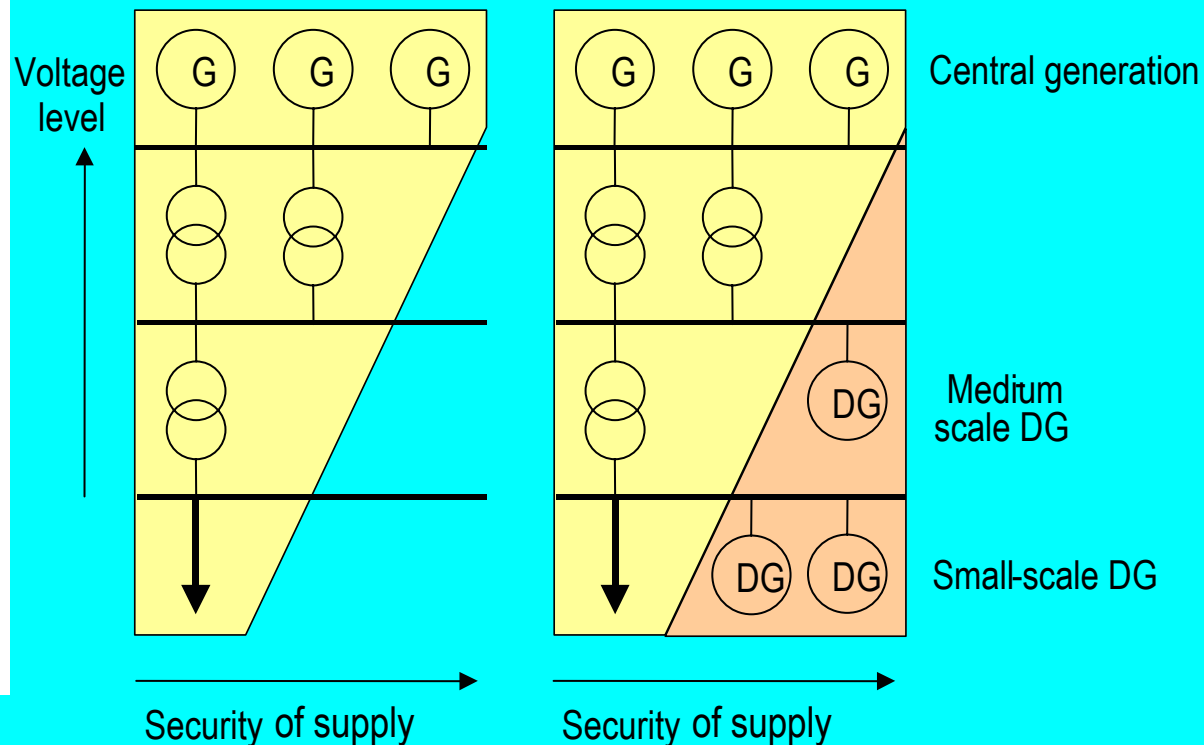
⇒ 1/3 less consumption of fossil sources of energy



Potential for DG to improve service quality



Distribution of CMLs





Network Benefits – Value of Micro Generation

~ .02-.04 €/kWh

Central Generation

~.03-.05 €/kWh

Transmission

HV Distribution

~ .05-.07 €/kWh

MV Distribution

~.1-.15 €/kWh

LV Distribution

***Micro
Generation***



Technical Challenges for Microgrids

- Relatively large imbalances between load and generation to be managed (significant load participation required, need for new technologies, review of the boundaries of microgrids)
- Specific network characteristics (strong interaction between active and reactive power, control and market implications)
- Small size (challenging management)
- Use of different generation technologies (prime movers)
- Presence of power electronic interfaces
- Protection and Safety



Market and Regulatory Challenges

- coordinated but decentralised energy trading and management
- market mechanisms to ensure efficient, fair and secure supply and demand balancing
- development of islanded and interconnected price-based energy and ancillary services arrangements for congestion management
- secure and open access to the network and efficient allocation of network costs
- alternative ownership structures, energy service providers
- new roles and responsibilities of supply company, distribution company, and consumer/customer



MICROGRIDS Project

“Large Scale Integration of Micro-Generation to Low Voltage Grids

Contract : ENK5-CT-2002-00610

GREAT BRITAIN

- UMIST
- URENCO

PORTUGAL

- EDP
- INESC

SPAIN

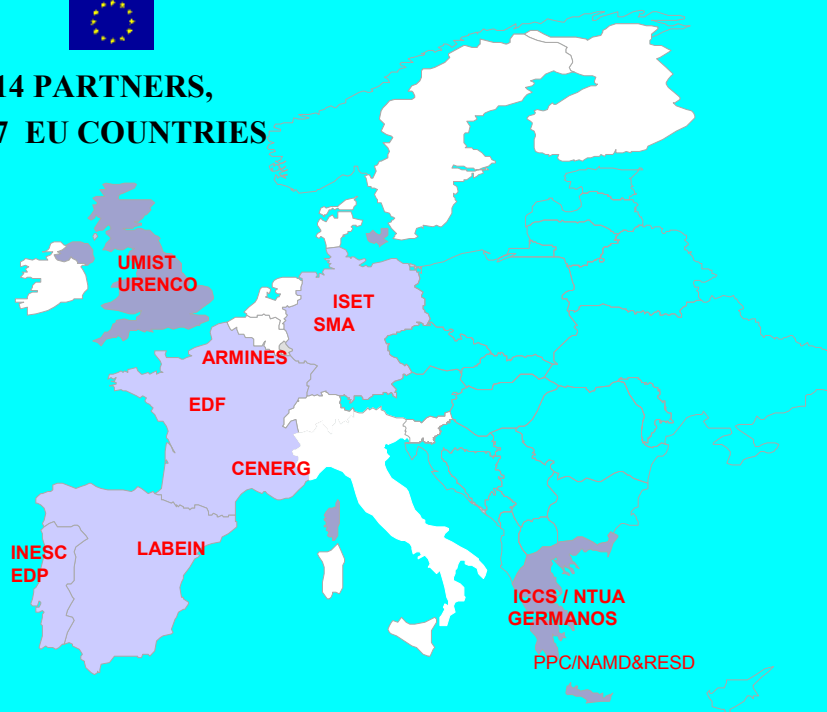
- LABEIN

NETHERLANDS

- EMforce



14 PARTNERS,
7 EU COUNTRIES



GREECE

- **NTUA**
- PPC /NAMD&RES
- GERMANOS

GERMANY

- SMA
- ISET

FRANCE

- EDF
- Ecole des Mines de Paris/ARMINES
- CENERG

<http://microgrids.power.ece.ntua.gr>

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R&D Objectives

- Contribute to increase the share of renewables and to reduce GHG emissions;
- Study the operation of Microgrids in normal and islanding conditions;
- Optimize the operation of local generation sources;
- Develop and demonstrate control strategies to ensure efficient, reliable and economic operation;
- Simulate and demonstrate a Microgrid in lab conditions;
- Define protection and grounding schemes;
- Define communication infrastructure and protocols;
- Identify legal, administrative and regulatory barriers and propose measures to eliminate them;



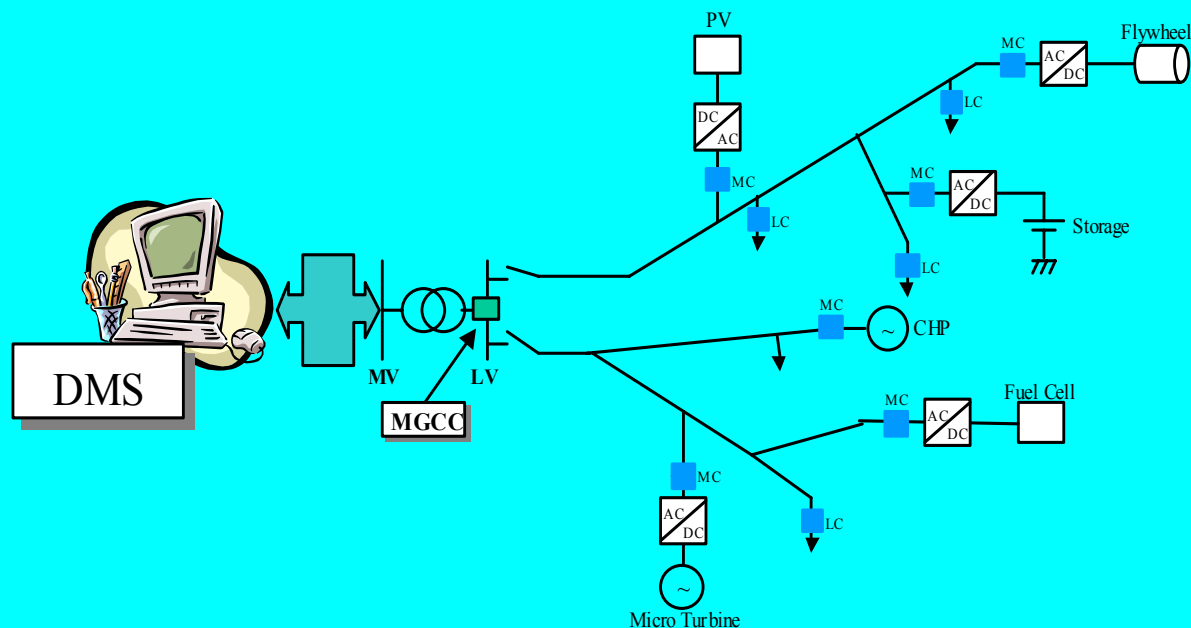
Microgrids Highlights

- Control philosophies (hierarchical vs. distributed)
- Energy management within and outside of the distributed power system
- Device and interface response and intelligence requirements
- Permissible expenditure and quantification of reliability benefits
- Steady State and Dynamic Analysis Tools



Microgrids – Hierarchical Control

MicroGrid Central Controller (MGCC) promotes technical and economical operation, interface with loads and micro sources and **DMS**; provides set points or supervises LC and MC; **MC and LC Controllers**: interfaces to control interruptible loads and micro sources

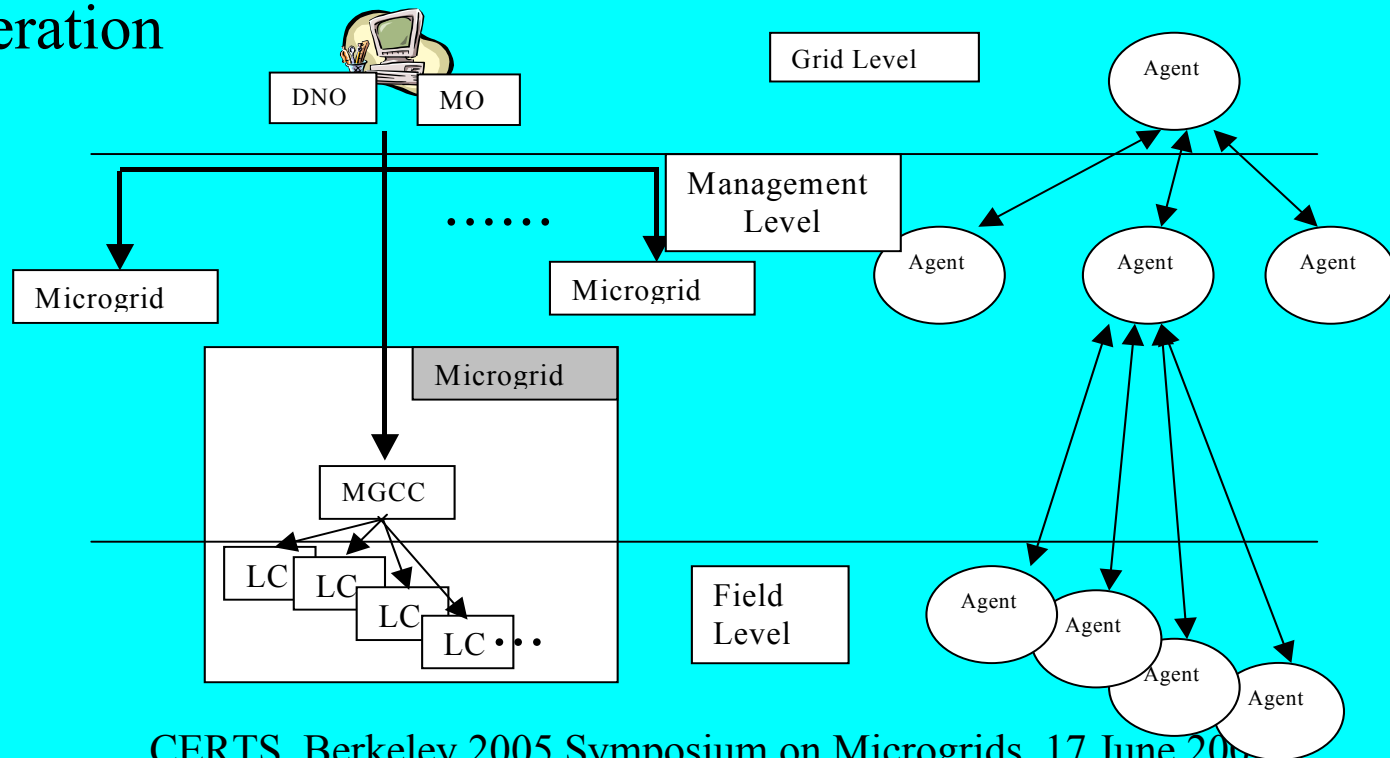


Centralized vs.
Decentralized
Control



MultiAgent System for Microgrids

- Autonomous Local Controllers
- Distributed Intelligence
- Reduced communication needs
- Open Architecture, Plug n' Play operation
- FIPA organization
- Java Based Platforms
- Agent Communication Language





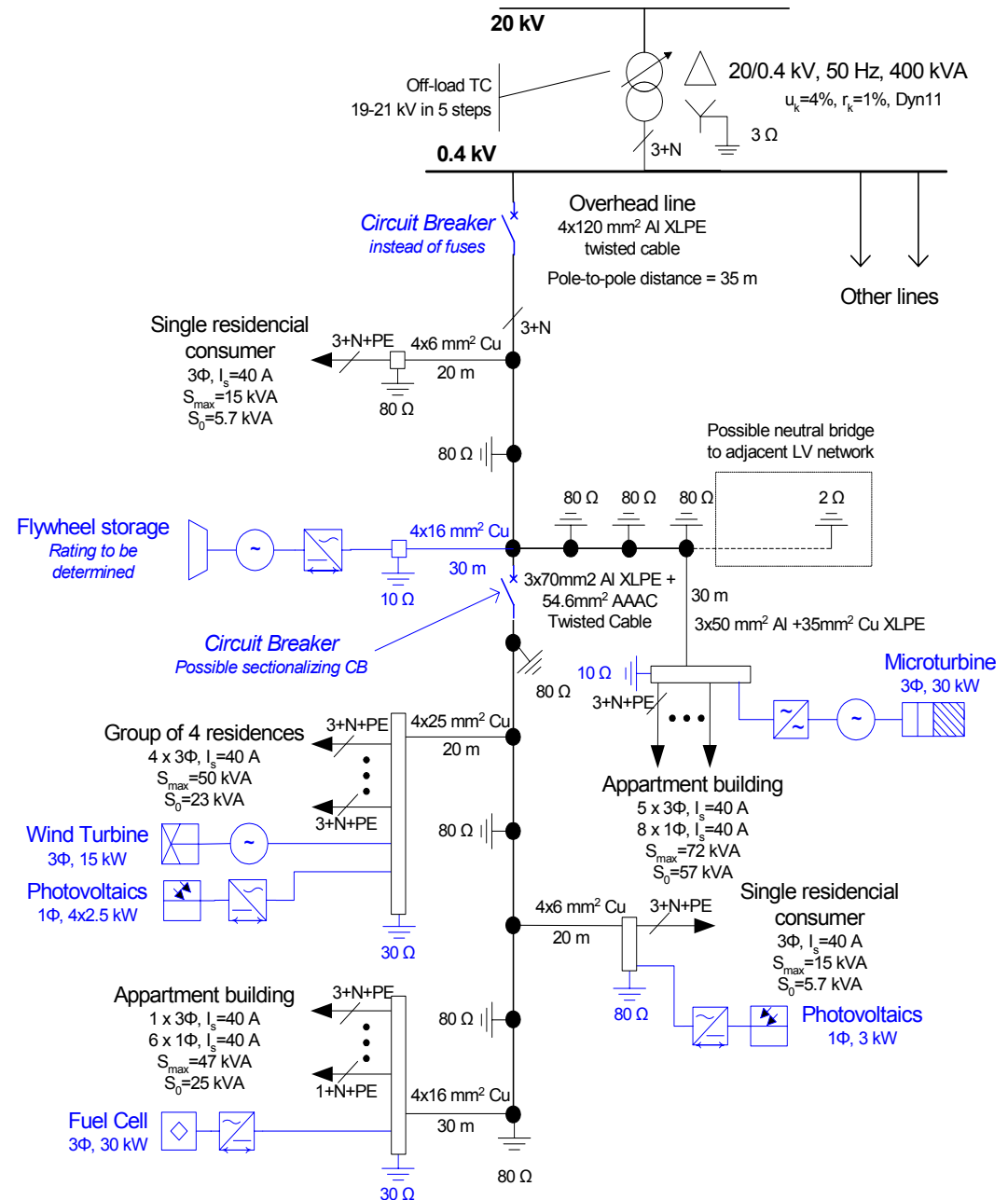
Participation of Microgrids in Energy Markets

- Microgrid Serving its own needs using its local production, when financially beneficial (**Good Citizen**)
MGCC minimises operation costs based on:
 - Prices in the open power market
 - Forecasted demand and renewable power production
 - Bids of the Microgrid producers and consumers.
 - Technical constraints
- Microgrid buys and sells power to the grid via an Energy Service provider (**Ideal Citizen**)
MGCC maximizes value of the Microgrid, i.e. maximizes revenues by exchanging power with the grid based on similar inputs



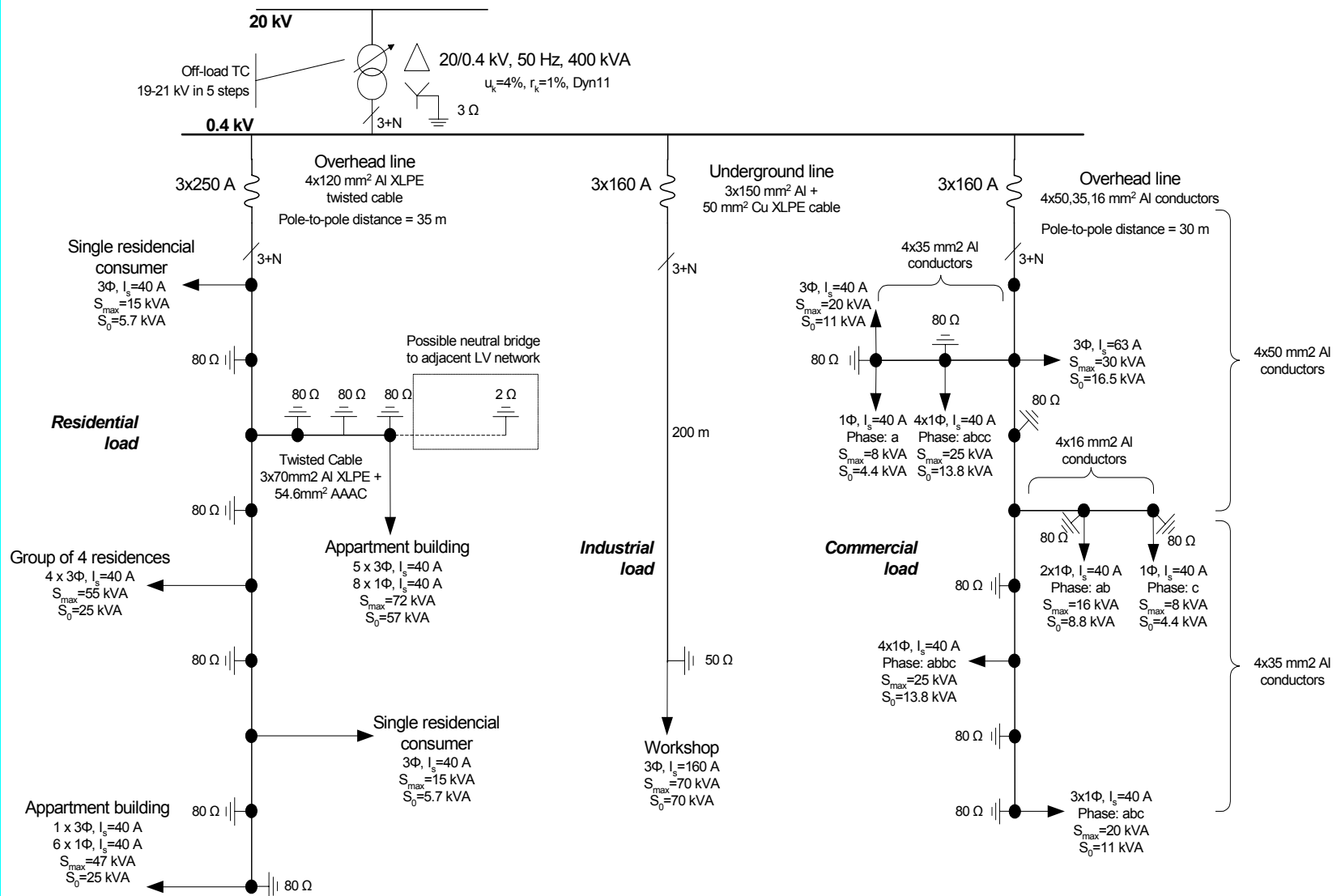
Study Case LV Feeder with DG sources

CERTS, Berkeley

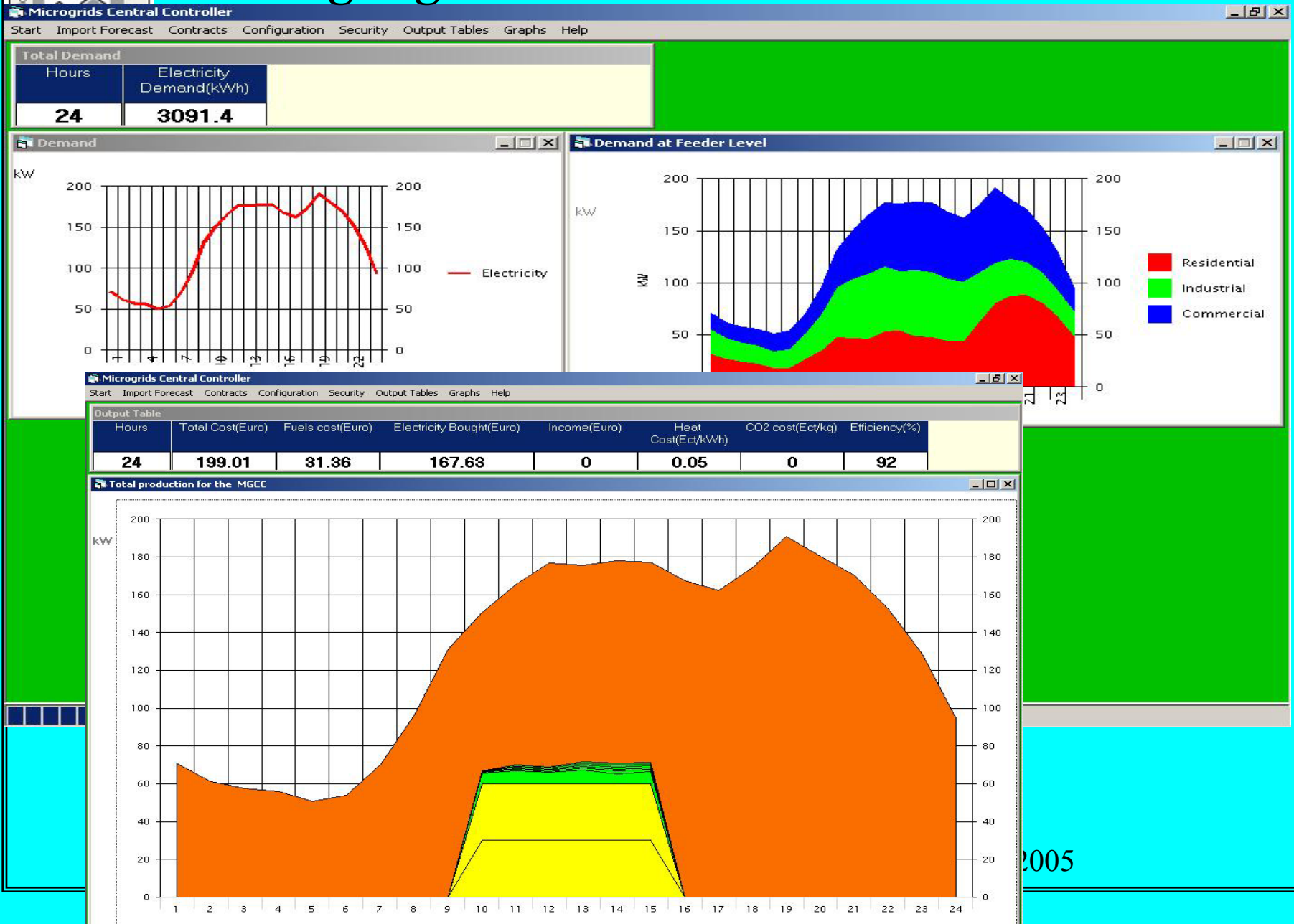




LV network with multiple feeders



Highlight: MGCC Simulation Tool



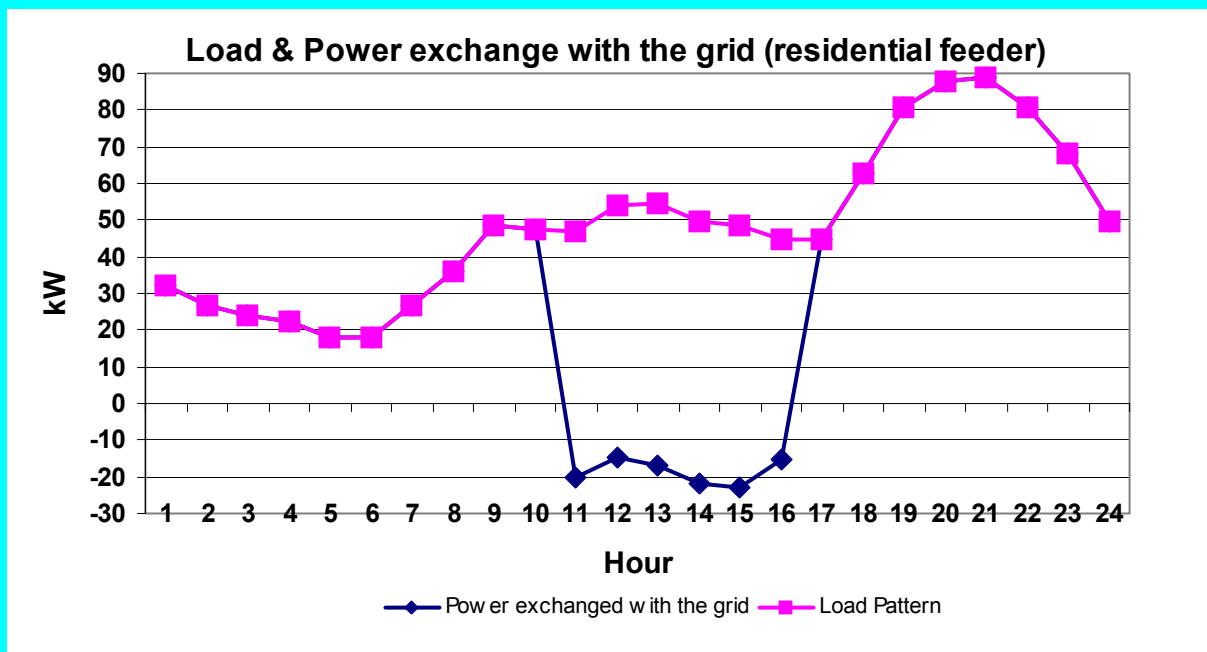


Residential Feeder with DGs

Good Citizen Cost Reduction : 12.29 %

27% reduction in CO₂ emissions

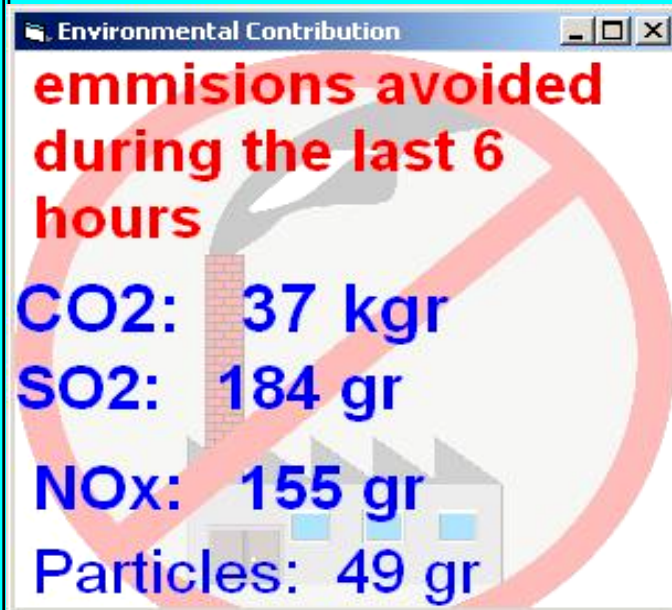
Model Citizen Cost reduction : 18.66%



Environmental Benefits



- Average values for emissions of the main grid
- Data about emissions of the μ -sources.



27% reduction in CO₂ emissions
due to policy1

Maximum reduction in CO₂
emissions 548kgr/day- 22.11%
higher cost



Highlight - Permissible expenditure to enable islanding

Customer Sector:	Residential	Commercial
Annual benefit =	1.4 £/kW _{pk}	15 £/kW _{pk}
Net present value =	15 £/kW _{pk}	160 £/kW _{pk}
Peak demand =	2 kW	1000 kW
Perm. expenditure =	£30	£160,000
MicroGrid (2,000kW)	£30,000	£320,000



Highlight: Reliability Assessment

- System Maximum Load Demand: 188 kW
- Capacity of System Infeed: 210 kW (100%)
- Installed DGs: 15 kW Wind, 13 kW PVs, 30 kW Fuel Cells, 30 kW Microturbines

	FLOL (ev/yr)	LOLE (hrs/yr)	LOEE (kWh/yr)
Infeed Capacity 100%			
(no DGs)	2,130	23,93	2279,03
Infeed Capacity 80%			
(no DGs)	58,14	124,91	3101,52
Infeed Capacity 80%			
(with Wind + PV)	14,02	41,67	2039,41
Infeed Capacity 80%			
(all DGs)	2,28	15,70	716,36

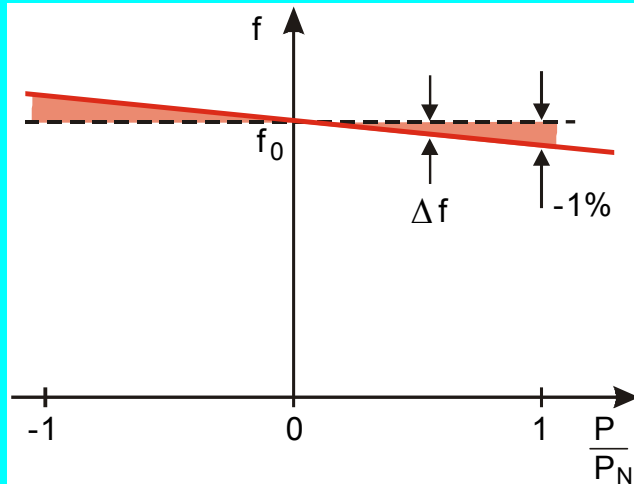


Reliability Assessment – continued

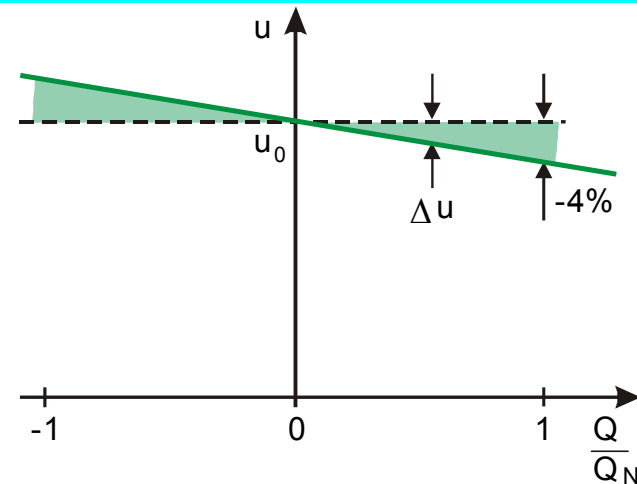
	FLOL (ev/yr)	LOLE (hrs/yr)	LOEE (kWh/yr)
Infeed Capacity 90%			
(no microsources)	8,52	31,08	2313,77
Infeed Capacity 90%, system load 207 kW (+10%)			
(no microsources)	44,10	92,75	3073,84
Infeed Capacity 90%, load 207 kW (with Wind + PV)	11,35	36,69	2232,54
Infeed Capacity 90%, load 207 kW (all microsources)	2,305	16,55	911,68



Parallel operation of inverters



Frequency droop

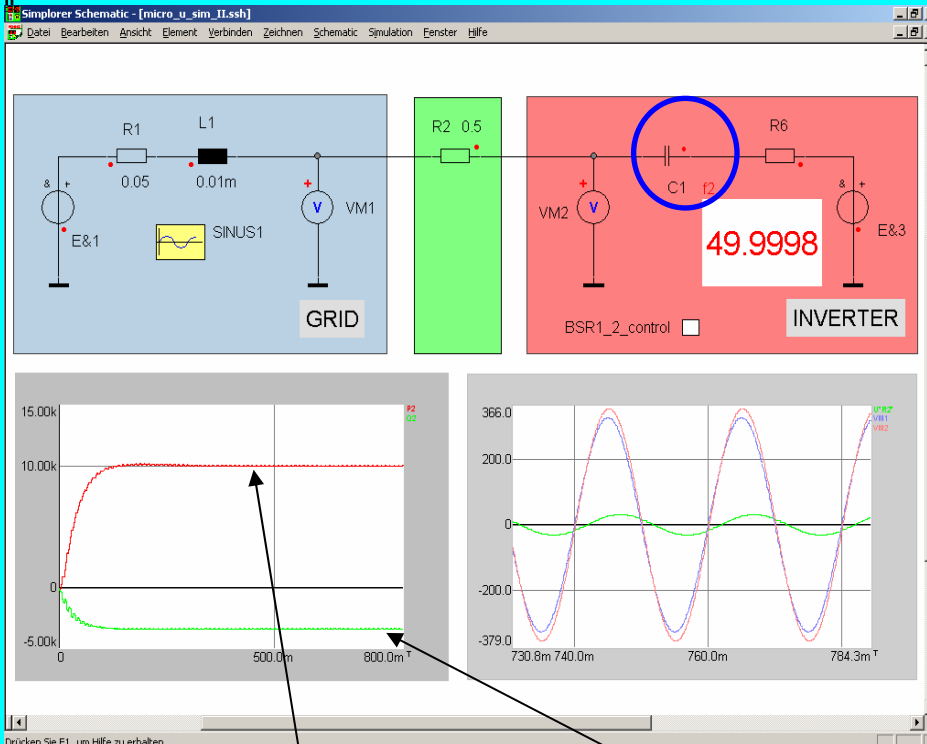


Voltage droop

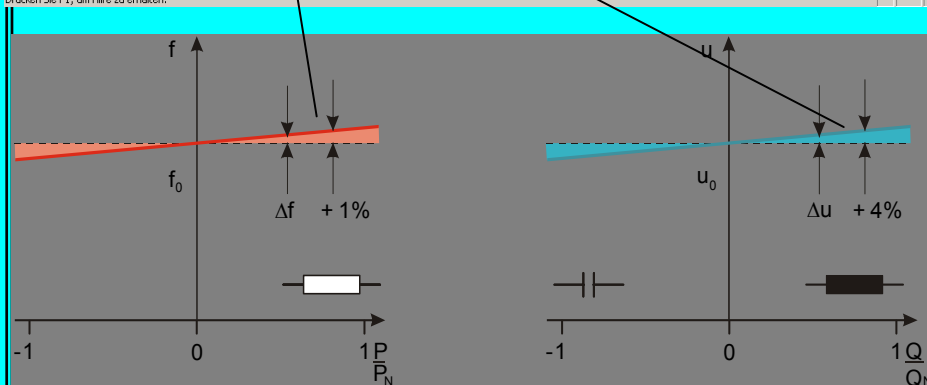
- Droops for synchronising inverters with frequency and voltage
- Frequency and voltage of the inverter is set according to active and reactive power.



Voltage Regulation and Active Power control through droop



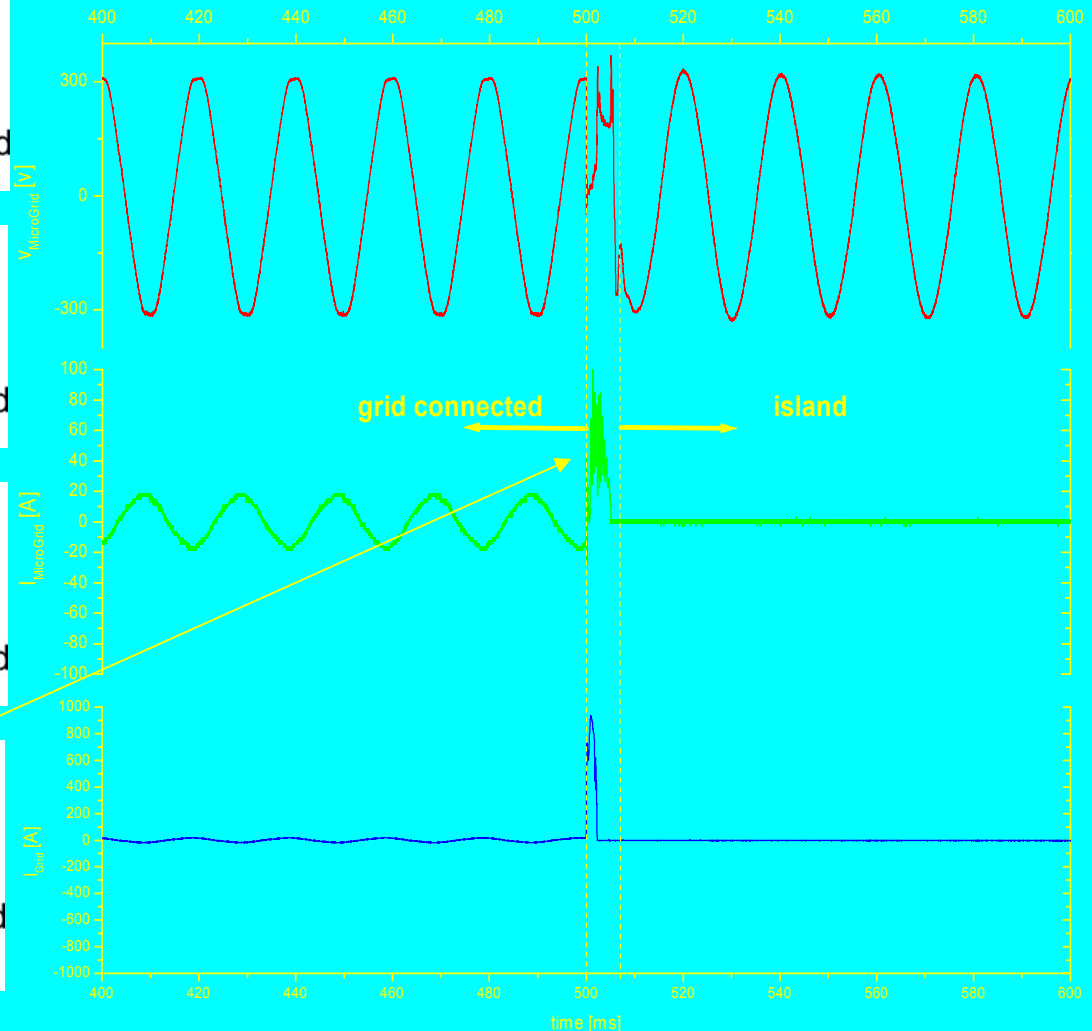
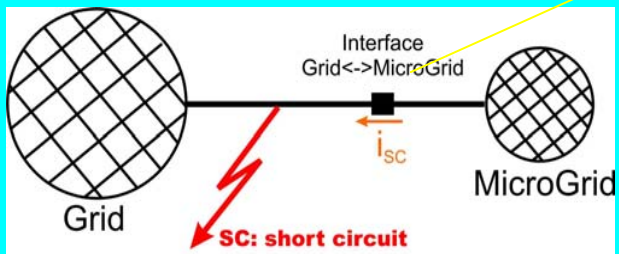
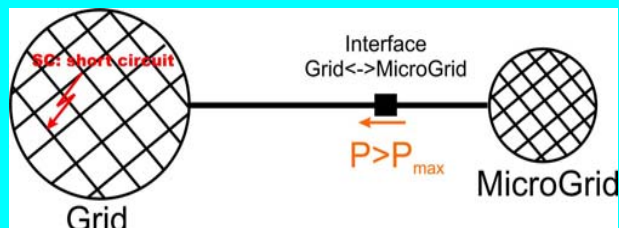
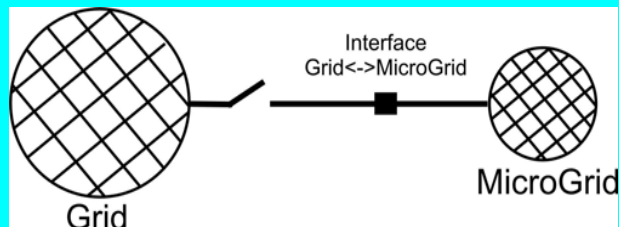
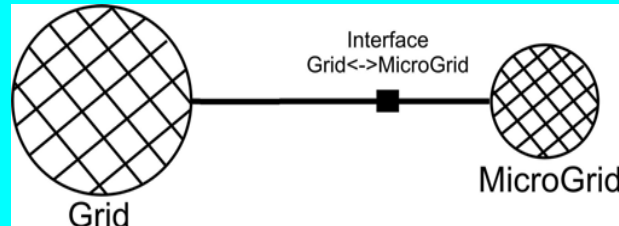
- Applied droop concept is based on inductive coupled voltage sources.
- In a LV-grid components are coupled resistive, thus voltage determines the active power distribution
- There are two effects of droops
 - **direct** (inductive coupling)
 - **indirect** (resistive coupling)
- The „indirect“ effect requires droops, which have the same sign for the frequency as well as the voltage droop and therefore the stable operation point is „in phase“.



The compensation of lines was simulated and is recommendable. Over-compensation has to be avoided!



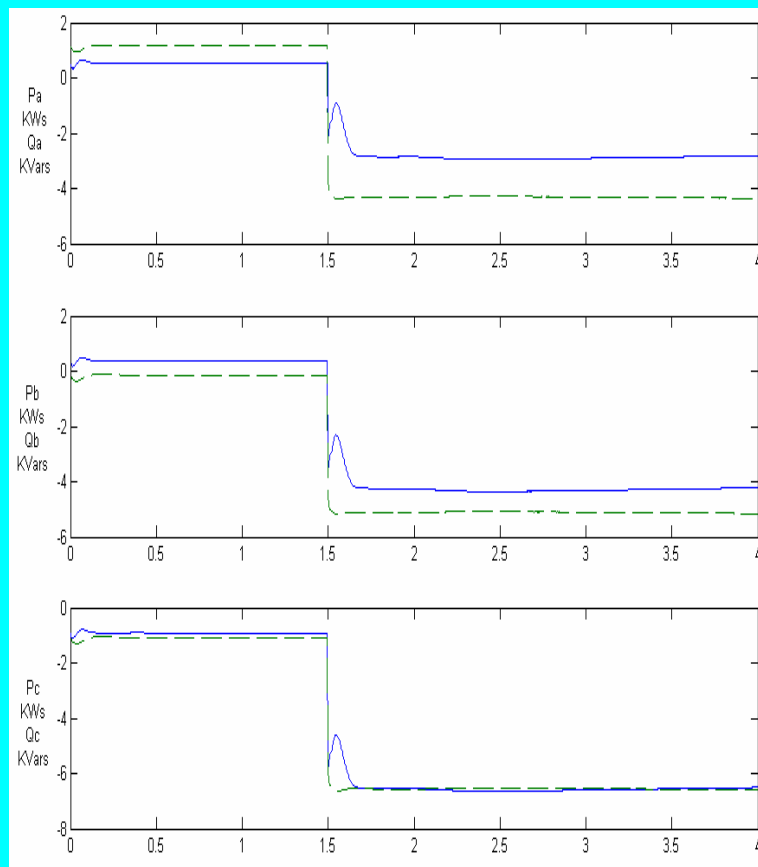
Development of Electronic Switch



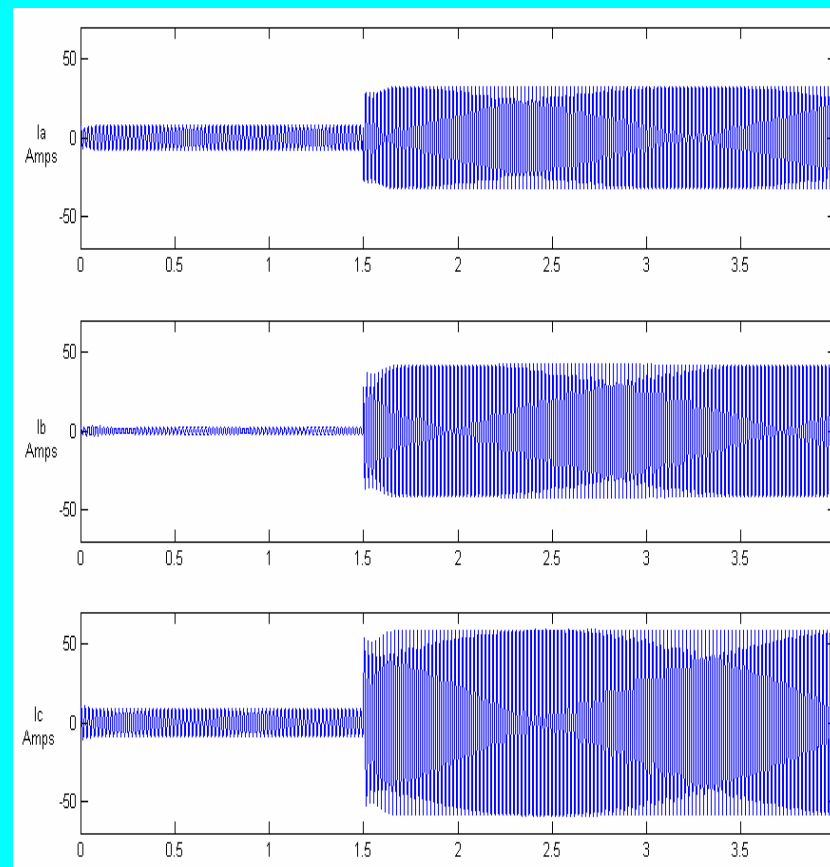


Highlight: Modelling and Simulation

Two battery invs + two PVs + one WT - Isolation + wind fluctuations



P,Q per phase Battery Inverter A



I per phase Battery Inverter A



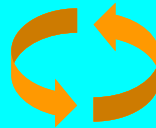
MORE MICROGRIDS

Advanced Architectures and Control Concepts for More Microgrids

Proposal/Contract no.: PL019864

RESEARCH INSTITUTES & UNIVERSITIES (6)

ICCS/NTUA (GR)
UMIST (UK)
INESC Porto (PT)
ISET (D)
LABEIN (ES)
ARMINES (F)



MANUFACTURERS (8)

SIEMENS (D)
ABB (S)
SMA (D)
EMforce (NL)
GERMANOS (GR)
ANCO (GR)
ZIV (ES)
I-Power (UK)

UTILITIES & MICROGRID OPERATORS (7)

EDP (PT)
CRES (GR)
CONTINUON (NL)
MVV (D)
CESI (I)
ELTRA (DE)
LRPD (PL)

Total Budget 7.9 M€

EC Contribution 4.5M€



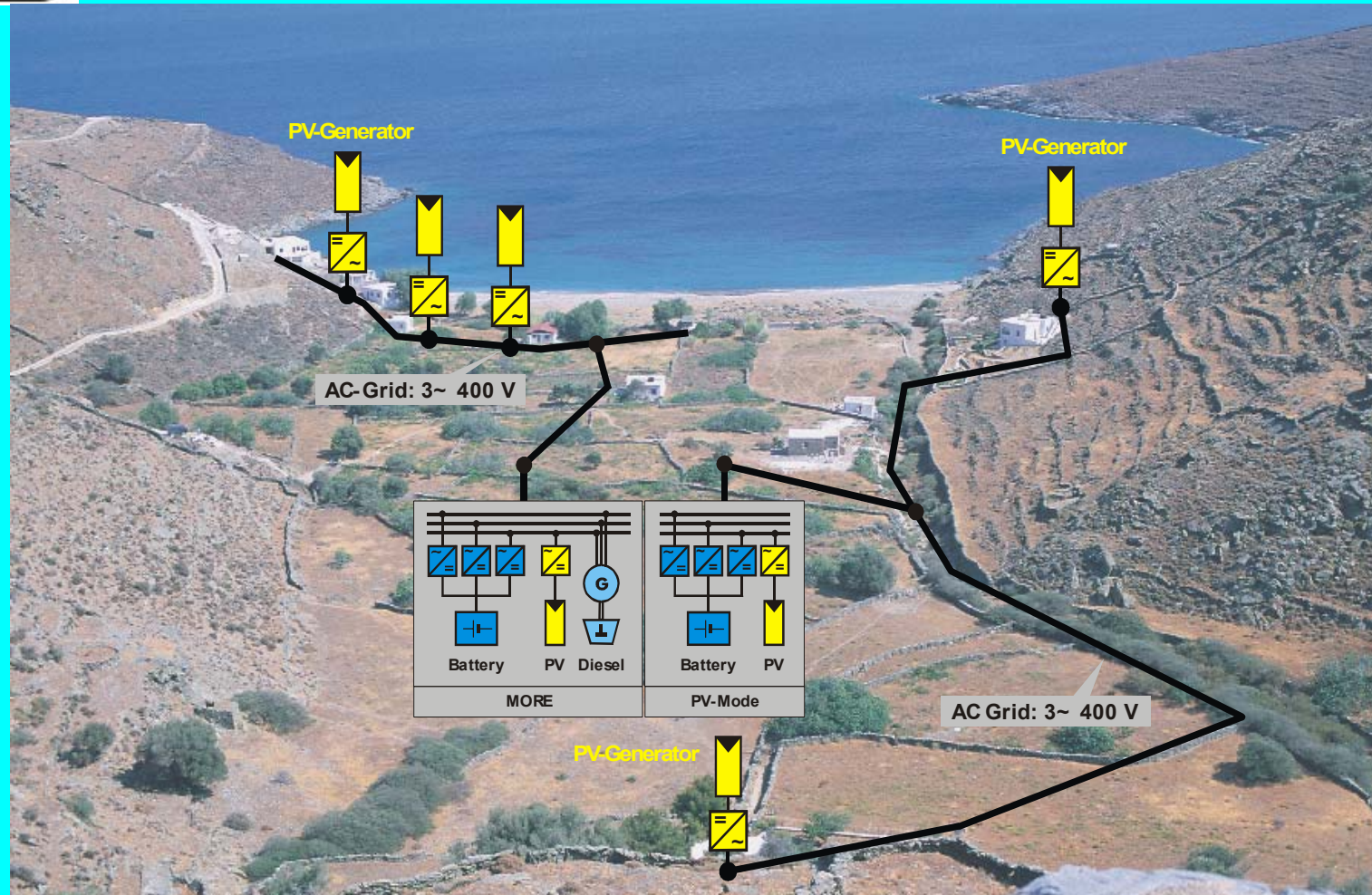
MORE MICROGRIDS

Workpackages

- WPA. Design of micro source and load controllers for efficient integration
- WPB. Development of Alternative Control Strategies (hierarchical vs. distributed) (**emphasis on De-centralized – MAS technologies**)
- WPC. Alternative Microgrids Designs
- WPD. Technical and Commercial Integration of Multi-Microgrids
- WPE. Standardization of Technical and Commercial Protocols and Hardware
- WPF. Field trials on actual Microgrids (7 Installations)
- WPG. Evaluation of the system performance on power system operation (Germany, Italy, Denmark, Netherlands, UK, Portugal, Greece, Poland...)
- WPH. Impact on the Development of Electricity Infrastructures (expansion Planning) (Germany, Italy, Denmark, Netherlands, UK, Portugal, Greece, Poland...)



Pilot Kythnos Plant



Supply of 12 buildings (EC projects MORE and PV-Mode)

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The Kythnos Microgrid





The Kythnos Microgrid





The Kythnos Microgrid



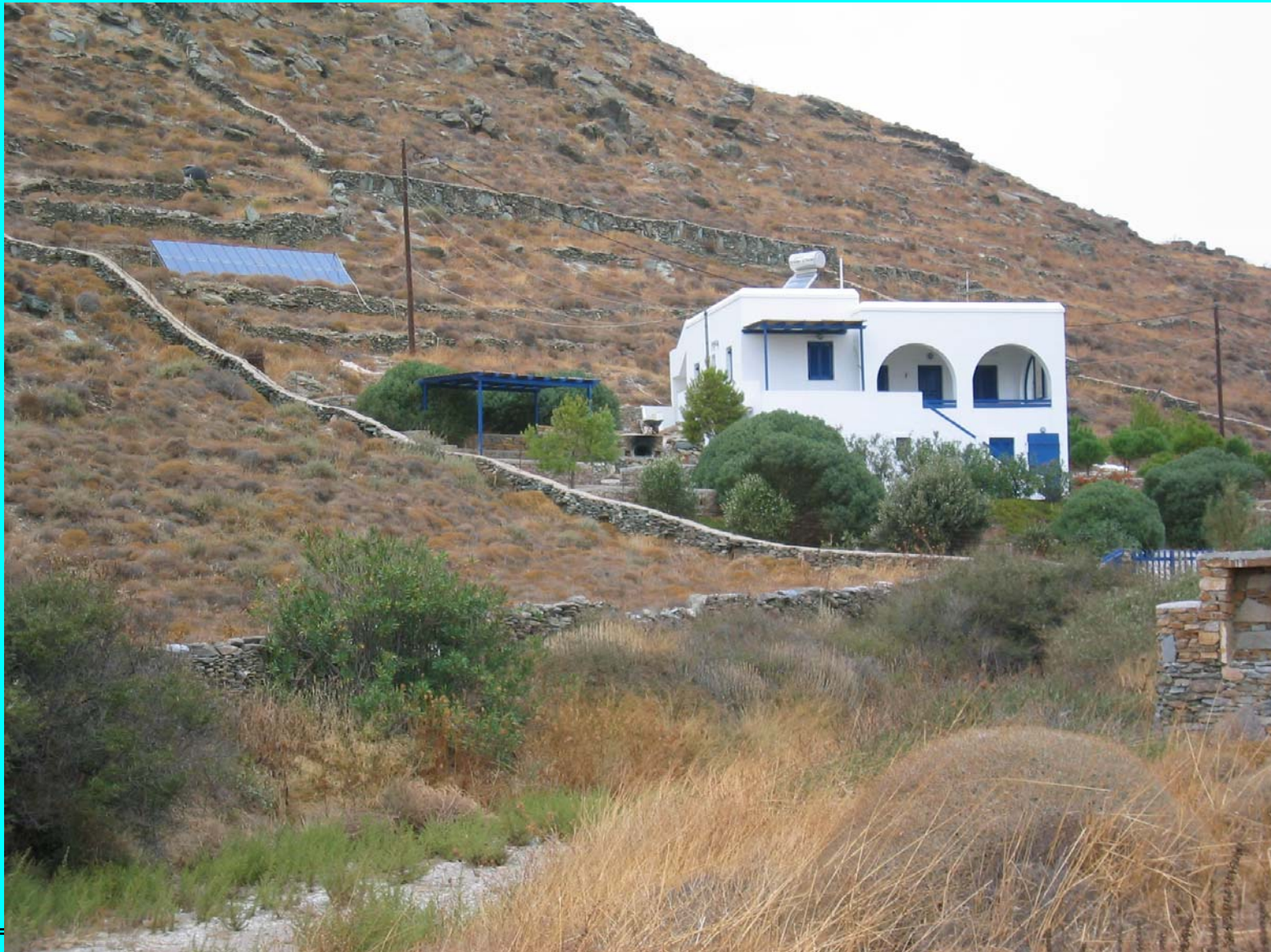


The Kythnos Microgrid





The Kythnos Microgrid





The Kythnos Microgrid





Conclusions

- Microgrids: A new paradigm for future power systems
- Distinct advantages regarding efficiency, reliability, network support, environment, economics
- Challenging technical and regulatory issues
- Needs for Field Testing and Benefits Quantification

<http://microgrids.power.ece.ntua.gr>